PHOTOGRAMMETRY FOR DIGITAL HAND SURFACE CAPTURE IN SWIMMING PERFORMANCE STUDY

Albert K. Chong

School of Surveying, University of Otago, Dunedin, New Zealand.
Chonga@albers.otago.ac.nz

Commission V

KEY WORDS: Crawl swimming, replica hand, stereo-photography, underwater photography

ABSTRACT:

The paper describes an application of close-range photogrammetry in the study of the human hand for propulsion in competitive swimming. The study involved the capture of 3-D surface data and modelling of a real and a replica hand. Both real and replica models were used in computer simulation to determine the propulsion parameters for high performance swimming. Custom-made control frame was used to provide accurate object-space control of the stereo-photography. In addition, the control frame was used to connect both sides of the hand into one coordinate system. A two-camera and a four-camera configuration were developed for the photography. The latter was used in the real hand photography and under-water stereo-photography. Results of the study showed that the surface of the replica has an undulating roughness of about 1.0 mm. However, the total error of the computed surface area was less than 1.5 cm^2 or 0.85%. Consequently, the error of the surface topography of the replica was negligible and the resulted error in the computation of the propulsion parameters was minimal.

1. INTRODUCTION

The objective of the paper is to discuss a method used to obtain surface topography of a real and a replica hand using digital stereo-photogrammetric technique. Replica is suitable for underwater testing because the crawl geometry can be repeated as often as needed and pressure sensors can be installed under the artificial skin. Generally, replicas were used to determine the propulsion parameters of real hands.

Propulsion is one of the key factors determining performance in human competitive swimming. Counsilman (1968) was one of the first researchers to apply physical principles to determine the mechanism of propulsion in front crawl swimming. Toussaint (2006) argued that the complex hand patterns would resemble a hydrofoil generating both lift and drag forces (figure 1). Accordingly, the lift (L) and drag (D) would take the following forms:

$$L = \frac{1}{2}\rho\mu^2 C_L S \text{ and } D = \frac{1}{2}\rho\mu^2 C_D S \qquad (1)$$

where C_L and C_D are coefficient of lift and drag, ρ is the density of water, μ is the swimming velocity and S is the wet surface area. As shown in the equation, accurate determination of the surface topography and surface area of the hand is vital in the study of lift and drag. Consequently, our task is to determine the surface area of the hand.

Moreover, Ellington (1995) argued that in maximizing the propulsion force, the fingers should be held tight so that the surface area on the levers is maximized and the most water is pulled. The research involves experimenting with finger-tightly-squeezed-together. Most experiments involved using replica hands which were packed with pressure sensors, for testing under the water. Subsequently, the initial study was carried to determine the correctness of the replica surface topography compared with the real hand.

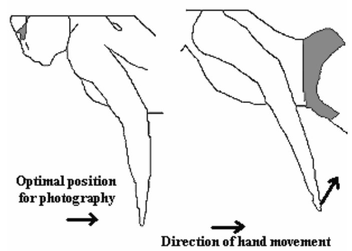

Figure 1. Crawl swimming. Note the optimum position of the hand for the study of drag and lift forces.

By and large, the close range photogrammetry technique was considered to be the most appropriate for accurate 3D surface data capture because high-speed photography captures the images of both sides of a hand instantly. Laser scanning was considered as an alternative. The advantages of Laser scanning are: 1) high accuracy; and 2) high efficiency (Bernardini et al 2001; Harrison et al. 2004; Marmulla et al. 2004). The drawbacks are: 1) a scan takes 0.3 second or more; 2) a back and front scan of a hand requires either two setups or two scanners working simultaneously; and 3) the system does not work well when the hand is immersed in water. The drawbacks make the system less practical and conceivably more expensive than conventional stereo-photography. Since both photogrammetric hardware and software and expertise are also readily available at the research institute, in addition to its suitability for underwater environment, it was practical to select the photogrammetric technique. As a result, no further study was given to the laser scanning technique.

There are numerous articles reporting the use of photogrammetry for mapping and 3-D surface data capture of the human body and its extremities. A few interesting examples of recent publications are: 1) craniofacial mapping (Majid *et al*. 2005); 2) under-water hand study (Toussaint 2005); 3) body surface and body parts (D'Apuzzo, N. 1998; 2001; 2003); 4) back of trunk (Newton and Fanibunda 1996); and 5) whole body modelling (Pascal *et al*. 1998). Among the many advantages, photogrammetry has an unique benefit in 3-D data capture because photography can be obtained for objects immersed in water (Toussaint 2005). The work undertaken in the swimming study also included photography under water.

2. EQUIPMENT AND SOFTWARE

2.1 Precision invar scale bar, calibration test field and object-space control frame

Figure 2 shows a calibration test field and a high precision invar scale bar. A custom-built aluminium control frame depicted in figure 3 was used as the object-space control for the project. The test field consists of rows of retro-targets fastened to the top surface of rods at various heights and the rods are fastened on to a piece of rigid 20 mm thick plastic board.

The aluminium frame consists of retro targets glued to the front and back of a rigid rectangular frame. Small spherical balls attached to short steel stems were fastened on to the inner side of the rectangular frame as shown in figure 3. The balls provided a means to transfer the front coordinate reference system to targets at the back.

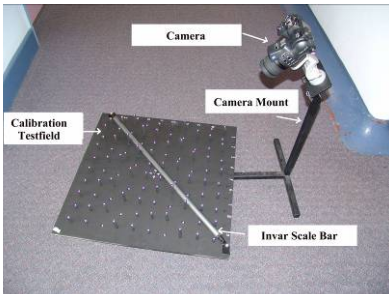

Figure 2. A calibration test field and a custom-made camera mounting device.

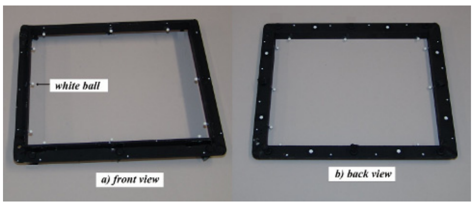

Figure 3. An object-space control frame for the project. Note that a similar version (top bar removed) was used for the underwater photography.

2.2 Replica hand

A swimmer's right hand was used in the study and is shown in figure 4. A replica hand was prefabricated using resin which has the elasticity of human skin, flesh and muscles (Toussaint 2005). Pressure sensors were attached to the hand (Kudo 2005) as shown in figure 5. The replica hand was used in the study which involved a flow channel or flume (figure 6). In the flow channel, the replica hand resembles a real hand engaged in crawl swimming. The pressure sensors measure the pressure (drag) created by the pull of the hand through water (based on the flow of the water in the flume in cumec). The position of the sensors and the topography of the surface of the hand are required for the research.

2.3 Digital cameras and remote shutter control

Four cameras were needed for the research. Although the swimming research team did not specify any object-space measurement accuracy, it was considered that a high quality off-the-shelf camera should be used for the stereo-photography. Consequently, Sony digital Cyber-shot FSC-828 cameras were considered the most suitable. Calibration showed that the camera had a 8.8 mm by 6.6 mm CCD format and a resolution of 3264 by 2448 pixels. Subsequent computation showed that the estimated object-space measurement precision using the maximum wide-angle focal length of 7.1 mm and an object distance of 600 mm was 0.25 mm.

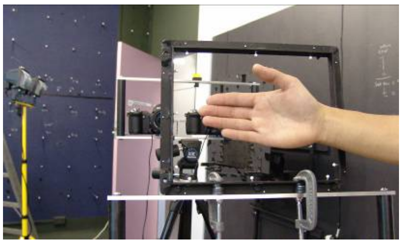

Figure 4. A typical stereo-photo of the real hand.

Figure 5. A typical stereo-photo of a replica hand.

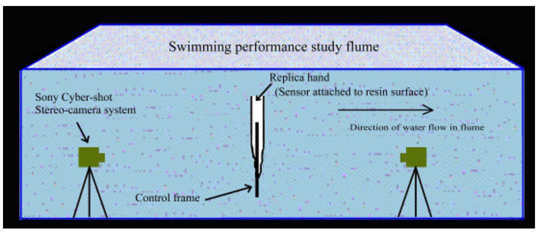

Figure 6. Under water stereophotography. Note the location of the control frame and the replica hand.

A four-camera shutter control device (marketed as LANC Shepherd camera control) was used to achieve simultaneous photography. The achievable synchronized timing was in the order of a few hundredths of a second. The device was considered highly essential for underwater photography.

2.4 Photogrammetric and Cad software

Australis bundle adjustment was used in the camera calibration and in coordinating the targets of the control frame. Automated and manual 3-D spatial capture of the topography of the hand was carried out on an optical-viewing DVP workstation and its suite of software. Cad 12d software was used for the spatial data editing (DVP output) and for the generation of 3-D models of the hand. Various "swimming performance analysis" software were also used in the study. However, the analysis was performed by the specialists at the School of Physical Education (PhD candidate Mr Shigetada Kudo). The result was not available at the completion of the paper.

3. METHODOLOGY

3.1 Calibrating the test field and object-space control frame

The coordinate of the targets on the test field and the control frame (including the steel ball) were obtained using multi-convergent images and photogrammetric bundle adjustment techniques. The process involved: 1) placing two scale bars and the control frame (front view) on the test field; 2) photographing the arrangement in (1); 3) setting up the control frame and camera as shown in figure 3; and 4) photographing the control frame (back and front views). The same procedure was used in the under-water camera calibration (Chong and Strafford 2002).

Bundle computation of the photographs, to obtain 3-D coordinates of targets was carried out in a similar sequence as the photography and it involved: 1) coordinating targets of the test field and the control frame (front view); and 2) coordinating targets of the control frame (back view) and the steel balls. The scale bars were used as object-space scale controls. An additional computation was needed to transform the coordinates of the back targets to conform to the reference system required by the DVP workstation. After the 'back view' 3-D model was generated, a reverse transformation was carried out, thus allowing the back model to be coupled to the front model. Australis bundle adjustment software was used in the computation.

3.2 Camera lens calibration

The cameras were calibrated separately. To ensure repeatable focal-length (PD) setting of the cameras for a prolonged period of time, as required for the project, the PDs were set to 'maximum wide-angle (28 mm)" and the zoom and focus adjusting rings were taped down firmly. The calibration was carried out by mounting the camera on a standard calibration device (figure 2). The object distance was set to 600 mm which was the value used for the project. After taking the required number of convergent photos, bundle adjustment computed the camera lens parameters (Atkinson, 1996; Chong, 1999; Fraser, 2000). The lens parameters considered essential for the DVP workstation were: 1) PD; 2) PPA offsets; and 3) radial lens distortion parameters K_1 and K_2.

3.3 Real and replica hand stereo-photography

The swimmer's real hand (figure 4) and the corresponding replica (figure 5) were photographed in the laboratory. As shown in the figures, the hands were placed at a distance of 30 mm from the front of the control frame. A pair of cameras were mounted in front and another pair at the back of the hand. A 55% overlap was designed for the photography. Two independent pairs of stereophotographs (back view and front view) were taken of the real hand and the same was repeated for the replica hands. The configuration of the cameras and the object distances were kept the same throughout the experiment. The use of the same configuration and object-distance ensures similar design accuracy. As a result, the computed 3-D models of the real and replica hands could be compared in term of surface area and volume accuracy.

3.4 Stereo-digitizing on the DVP workstation

The type of spatial data captured from the stereo-photos was based on the 3-D modelling specifications required by 12d Cad software. As unique features (e.g. fold line) on the fingers and palm were needed for accurate surface topography comparison between the real and replica hand, it was necessary to stereo-digitize these features manually. The edge of the fingers and the palm were traced manually after completing the interior and exterior orientations of each stereomodel. Subsequently, a semi-automated contouring process generated spot heights in a grid pattern over the surface of the hand (figure 7). The data was imported into 12d for data editing and 3-D modelling. A contour plot of the heights was generated to check for errors.

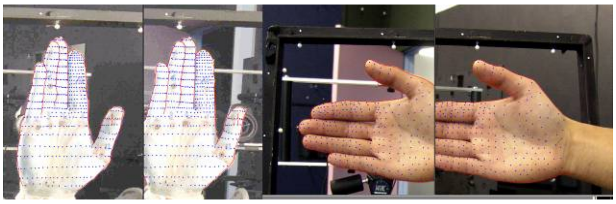

Figure 7. Digitizing the replica hand and real hand on a DVP workstation.

4. RESULTS AND ERROR ANALYSIS

Figure 8. shows a simplified 3-D model of the replica hand. The accuracy of the captured 3-D coordinate of the hands was 0.85 mm. A small sample of areas was selected for comparison. Identifiable points on the front and back of the palm were used to evaluate the models. These samples were used to compute the total error. The computed surface area shows that the surface of the replica has an undulating roughness of about 1.0 mm. However, the total error of the computed surface area was less than 1.5 cm^2 or 0.85%.

Figure 8. A simplified 3-D model of the replica hand

Further computation shows that the total error of the surface topography of the replica was negligible. Consequently, the error in the computation of the propulsion parameters was minimal.

5. DISCUSSION

By and large, texture-enhancing, automated stereo-matching and automated data capture is a routine photogrammetric operation in body surface mapping (D'Apuzzo 2003). However, our study required the use of traditional stereo-view digitizing to pick up features which could be useful in the study of surface irregularity. And we did not used surface-texturing technique because we need to see the folds and other features which could be used as markers for identification.

Nevertheless, underwater study required the use of retro targets on the skin for accurate identification, as water is a good absorption of light. The effect reduces the visibility of the skin surface. The result is poor depth perception.

6. CONCLUSION

The study involves precise surface measurement to determine the contribution of drag and lift in crawl swimming. Our method has an unique advantage in the study of underwater characteristics of the hand-surface because the technique could be applied to evaluate performance swimming. Accordingly, the use of photogrammetry in a swimming performance study still required, in an age of high accuracy laser-scanning technology.

The water pressure acting on the skin surface distorts the surface of the skin during swimming. A flattening effect increases the surface area and consequently, increases the drag and lift. Further research is necessary to determine such effects. However, it may be necessary to acquire a higher-resolution camera, special underwater lighting and retro-target for this type of study.

ACKNOWLEDGEMENT

The author acknowledges the help of the School of Physical Education PhD candidate Mr Shigetada Kudo for the technical information on swimming performance, the use of the replica hand and the photographs of his hand for the study.

REFERENCES

D'Apuzzo, N., 1998. Automated photogrammetric measurement of human faces. *International Archives of Photogrammetry and Remote Sensing*, Vol. 32 Part B5, pp. 402-407.

D'Apuzzo, N., 2002. Measurement and modeling of human faces from multi images. *International Archives of Photogrammetry and Remote Sensing*, Vol. 34 Part 5, pp. 241-246.

D'Apuzzo, N., 2003. Surface measurement and tracking of human body parts from multi station video sequences. *Institut für Geodäsie und Photogrammetrie Eidgenössische Technische Hochschule Zürich ETH Hönggerberg.* Zürich, Diss. Eth No. 15271, 161 pages.

Atkinson, K.B., (editor) 1996. *Close Range Photogrammetry and Machine Vision*, Whittles Publishing, 378pages.

Bernardini F., Martin, I.M. and Rushmeier, H., 2001. High-quality texture reconstruction from multiple scans. IEEE Transactions on Visualization and Computer Graphics, 7(4), pp. 318-332.

Chong, A.K., 1999. A Multipurpose Camera Calibration Range, *New Zealand Surveyor*, 289, pp. 19-22.

Counsilman, J.E., (1968). *Science of swimming.* Prentice-Hall, Englewood Cliffs, N.J. 457 pages.

Fraser, Clive, 2000. Developments in Automated Digital Close-Range Photogrammetry, *ASPRS 2000 Proceedings*. Washington. DC, In cd, 10 pages.

Harrison, J.A., Nixon, M.A., Fright W.R. and Snape, L. 2004. Use of hand-held laser scanning in the assessment of facial swelling: A preliminary study. *British Journal of Oral and Maxillofacial Surgery*, 42(1), pp. 8-17.

Marmulla, R., M¨uhlinga, J., L¨uthb, T., Eggersa, G., Hassfelda, S., 2004. Advanced surface-recording techniques for computer-assisted oral and maxillofacial surgery. *British Journal of Oral and Maxillofacial Surgery,* 42, pp.511-519.

Pascal Fua1, Armin Gruen, Ralf Plänkers, Nicola D'Apuzzo, and Daniel Thalmann, 1998. Human body modeling and motion analysis from video sequences. *International Archives of Photogrammetry and Remote Sensing*, Hakodate, Japan, Vol. 32 Part B5, pp. 866-873.

Thomas, P.R., Newton, I. and Fanibunda, K.B., 1996. Evaluation of a low cost digital photogrammetric system for medical applications. *International Archives of Photogrammetry and Remote Sensing*, Vienna. Vol. 31 Part B5, pp. 405-410.

Toussaint, H., 2005. An alternative fluid dynamic explanation for propulsion in front crawl swimming. www.coachesinfo.com/article/154. 10pages. (accessed 20th January 2006).